

March 15/86
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**STUDIES OF LAKES AND WATERSHEDS
IN MUSKOKA-HALIBURTON, ONTARIO:
METHODOLOGY (1976-1982)**

W.A.Scheider, R.A.Reid, B.A.Locke and L.D.Scott

DATA REPORT DR 83/1

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S78
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DATA REPORT SERIES

The data presented in this report were collected by staff of the Water Resources Branch of the Ontario Ministry of the Environment as part of the Lakeshore Capacity Study or the Acid Precipitation in Ontario Study. This unreviewed report does not necessarily reflect the views or opinions of the Ontario Ministry of the Environment.

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Studies of Lakes and Watersheds
in Muskoka - Haliburton, Ontario:
Methodology (1976 - 1982)

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Data Report DR 83/1

PREFACE

The unpublished Data Report Series is intended as a readily available source of basic data collected for lakes and watersheds in the Muskoka-Haliburton area of Ontario. These data were collected as part of the Lakeshore Capacity Study and/or the Acid Precipitation in Ontario Study.

The limnological portion of the Lakeshore Capacity Study (1975-81) was initiated to investigate the relationships between lakeshore development and lake trophic status in low ionic strength Precambrian lakes. The Acid Precipitation in Ontario Study (1979-present) was initiated, in part, to investigate the effects of the deposition of strong acids on aquatic and terrestrial ecosystems in Ontario. The primary findings of these studies have been and will continue to be published as reviewed papers and technical reports.

ABSTRACT

A summary of the methods routinely employed for hydrological gauging and lake, sediment, stream, precipitation and biological sampling in the Muskoka-Haliburton study area during 1976-1982 is given.

Scheider, W.A., R.A Reid, B.A. Locke and L.D. Scott 1983. Studies of lakes and watersheds in Muskoka-Haliburton, Ontario: Methodology (1976-1982). Ont. Min. Envir. Data report DR 83/1.

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Figure 1. Location of the principal study lakes, streams (1 - Beech 1, 2 - 12 Mile 1 N, 3 - 12 Mile 1 S, 4 - Duck 1, 5 - Moose 1, 6 - Haliburton 12, 7 - Head 1, 8 - Trading Bay 1, 9 - Paint 1), precipitation stations (see Figure 4) and meteorological stations (M1 - Huntsville, M2 - Dwight, M3 - Dorset, M4 - Vankoughnet, M5 - Haliburton, M6 - West Guilford).

Figure 2. Stage (m) vs. discharge ($L \text{ sec}^{-1}$) relationship for Harp 4 watershed for the period June 1976 - May 1980.

Figure 3. Mean-section method of calculating stream discharge.

Figure 4. Types of precipitation collected at each sampling location and periods of collector operation.

1. Introduction

This report outlines the field and laboratory methods employed by the Limnology Unit of the Ontario Ministry of the Environment in studies of lakes and streams in Muskoka District and Haliburton County during the period of 1976-1982. The studies were initiated as part of the Lakeshore Capacity Study (1975-1981) and continued as part of the Acid Precipitation in Ontario Study (1979-ongoing).

In both programs, two sets of study lakes were chosen. The "A" lakes were studied with the intent of constructing mass balance models to predict changes in lake chemistry and biota. The less intensively studied "B" lakes were chosen with the intent of following trend-through-time changes in lake chemistry and biota to allow testing of the models developed on the "A" lakes. Table 1 gives a list of the principal study lakes and their designation as "A" or "B" lakes. Additional lakes sampled as a part of the Acid Precipitation in Ontario Study will be listed in a future report.

2. Study Area

The locations of the principal study lakes and streams as well as precipitation and meteorological stations are given in Figure 1. Most lakes are underlain by Precambrian metamorphic silicate bedrock with thin Pleistocene glacial deposits. Glen Lake as well as Beech Inlet 1, Twelve Mile Inlet 1 N, Twelve Mile Inlet 1 S, Duck Inlet 1 and Moose Inlet 1 are

underlain by surficial deposits containing carbonate till. The area is forested with mixed deciduous-coniferous stands. A more detailed description of the geology of the area is given in Jeffries and Snyder (1983). A summary of selected morphometric data for the lakes is given in Table 2. Morphometric maps and more detailed data are given in Nicolls et al (1983).

3. Hydrological Methods

A. Precipitation

Daily precipitation depth used in the calculation of the water balances of the study lakes and watersheds was estimated from data measured at the closest Environment Canada meteorological stations (Table 3). If data were not available from the closest station, data from the next closest station were used. Precipitation depth was measured with a standard 10 cm. diameter rain gauge in the summer, and a snow board and ruler in the winter.

Weekly snow surveys were carried out at 4 sites on Harp Lake from December 1981 - April 1982 using either a Mount Rose or Utah sampler to measure snow depth and water equivalent. There were 6 plots per snow course, located in areas representative of the basin, about 50 m apart.

B. Streamflow

Watershed boundaries of all lakes and subwatersheds were delineated by stereoscopic study of airphotos. Where interpretation was difficult, the boundaries were checked by field observation. Weirs or flumes (Table 4) were installed on the major inlet streams, on the outlet stream of each of the calibrated 'A' lakes as well as on 9 additional streams entering non-calibrated lakes (export streams). Stage (water level) was recorded continuously at these sites with a Leupold and Stevens Type A Model 71 float operated recorder. Cold weather operation of the float recorders was made possible on some streams in some years by heating the stilling wells. Stage discharge curves (eg. Figure 2) were established for each weir and flume (Scheider et al. 1983). Discharge measurements were taken at weekly to bimonthly intervals except during periods of peak flow in spring when measurements were taken more frequently.

Discharge was measured using two methods. At low flow ($<8 \text{ L sec}^{-1}$), the entire volume of the stream was caught in a bucket for a measured time period as it passed over the weir notch. Measurements were taken in triplicate and the values averaged to obtain discharge. Alternatively, the stream velocity was measured for approximately one minute with either a Teledyne Gurley Pygmy Model 625, an Ott C2 or an Ott C31 current meter at 0.1 or 0.2 m intervals across the stream at 60% of stream depth. Discharge was calculated using the "mean-section" method diagrammed in Figure 3.

The continuous stage records were converted to continuous discharge using the STREAM programme (Water Survey of Canada 1977) , with assistance from the Hydrology and Monitoring Section, Ontario Ministry of the Environment.

The stream gauging programme was designed to yield an uninterrupted record of mean daily discharge. Where data were missing, mean daily discharge was estimated by one of the following methods -

- i) the mean daily discharge was equated to a measured (point in time) discharge or a discharge predicted from a staff gauge taken the same day.
- ii) the mean daily discharge was obtained by linear interpolation between a previous and subsequent measured value. This technique was used only if weather records and/or discharge data from a nearby stream showed that there was no major rainfall/runoff event in the period.
- iii) the mean daily discharge was predicted from a similar stream using an equation derived by linear regression of the mean daily discharges of one stream against those of another stream. The "most similar" stream was usually chosen from the regression yielding the highest correlation coefficient. A separate regression equation was calculated for each season of each year, the seasons chosen as June-August, September-November, December-February and March-May.

- iv) The mean daily discharge was estimated by visual observation of the stream. This last method was rarely used.

Runoff from a considerable proportion (14-100%) of the terrestrial drainage area of the 'A' lakes was not directly measured. These areas either drain directly into the lake via overland flow, drain via small, intermittent streams or drain via wide swampy streams that were difficult to gauge. We estimated the annual discharge for these areas on a lake by lake basis, using the mean value of the annual unit yield (unit runoff/precipitation depth) for the gauged watersheds on the lake. Red Chalk and Blue Chalk Lakes were considered jointly. The unit yield was multiplied by the annual depth of precipitation at the closest meteorological station and the area of the ungauged basin under consideration.

C. Storage

Changes in storage during the open water period were determined from lake level measurements made at approximately weekly intervals.

D. Evaporation

Net evaporation rates (evaporation loss - condensation gain) for the open water period of each lake were calculated as the residual term in the energy balance. Evaporation was assumed to be zero during the period of ice cover. The energy balance for a lake may be described by the equation:

$$R + P + F - G - S = LE + H \quad (1)$$

where: R = net radiation at the lake surface

P = heat exchange due to precipitation

F = heat exchange due to runoff into and out of lake

G = heat loss to lake sediments

S = change in heat storage in lakewater

H = sensible heat exchange between the lake surface and the atmosphere.

LE = latent heat exchange between the lake surface and the atmosphere where L = latent heat of vapourization (590 cal/gm) and E = water vapour exchange. A negative E indicates net condensation on the lake surface.

It can be shown that P, F and G are negligible terms in the balance for the eight "A" study lakes. Therefore, the energy equation simplifies to:

$$R - S = LE + H \quad (2)$$

The Bowen ratio (B) (Bowen 1926) is used to separate the terms LE and H as follows:

$$B = H/LE \quad (3)$$

and is independently estimated as:

$$B = \frac{T_w - T_a}{e_w - e_a} \quad (4)$$

where: T_w = surface water temperature

T_a = air temperature

e_w = saturation vapour pressure at T_w

e_a = saturation vapour pressure at T_a

Therefore:

$$LE = R - S/1+B \quad (5)$$

The evaporation calculations were carried out over time periods defined by the dates on which lake temperature profiles were taken (usually weekly). Daily evaporation for each period was calculated as total evaporation for the period/number of days in the period. Monthly evaporation was obtained by summing the daily values. The terms of the equations used in the calculation of evaporation, their definition and our method of estimating them are summarized in Ontario Ministry of the Environment (1982).

4. Lake Sampling for Chemical Analysis

A. Station Location

All routine samples were collected at the deepest spot in each of the single basin lakes and at the deepest spot in each of both

basins of Red Chalk Lake. Bathymetric maps were drawn at 2 m contour intervals from 20 - 30 sonar transects taken with a Furuno Mark III echosounder. Morphometric measurements were calculated using Hutchinson (1957).

B. Ice-free Period

Temperature of the lakes was taken at 1 m intervals to lake bottom (0.5 m intervals through the metalimnion) with a Whitney-Montedoro Model TC-5C thermistor. The depths of the epilimnion, metalimnion and hypolimnion were calculated on site from the temperature vs depth plot (Wetzel 1975).

Samples for chemical analysis were taken with a Cole-Parmer peristaltic pump using Tygon tubing at 2 m intervals to lake bottom commencing at 1 m below surface. An aliquot of water proportional to the volume of stratum represented was removed from each depth and added to an 8 L nalgene carboy. Aliquots from all depths were added to the carboy such that a single, volume weighted, composite sample was obtained for each of the epilimnion, metalimnion and hypolimnion of the lake. Under conditions of thermal homogeneity, water from all depths was pooled to give a single, volume-weighted sample representative of the entire lake. Separate samples were taken at 2 m intervals to the lake bottom for O_2 , pH and DIC.

Appropriate sample containers (Table 5) were filled by pouring the composite water through 102 μ m Nitex mesh to remove coarse

particulates. Samples were submitted for analysis to either the Dorset or Toronto laboratory depending upon sample perishability. Dissolved fractions were filtered in the field or at the Dorset laboratory through 0.45 μm Sartorius filter paper.

Intensive study lakes ("A" lakes in Table 1) were monitored weekly whereas sampling frequency on the "B" lakes was monthly or bi-monthly. The full suite of analyses (Table 5) was not performed on each sampling occasion.

C. Ice-cover Period

During the period of ice-cover, the "A" lakes were sampled monthly and the "B" lakes on two occasions. The sampling procedure was similar to that of the ice-free period with the following exceptions. A measurement of snow and ice thickness was taken at the sampling site and subsequent sampling depths were measured from the ice surface. Water was subsampled from the 8 L carboy at the Dorset laboratory rather than in the field. Where filtration of samples was required, this was performed in Dorset.

D. Analytical Methodology

All analytical techniques with the exception of those for Mn (Crowther 1978) and TP (Jeffries et al. 1979) are described in Ontario Ministry Environment (1981).

5. Sediment Sampling Methods

Sediment samples were collected from the "A" lakes using a K-B gravity corer (Brinkhurst et al. 1969) with clear Plexiglass core tubes having an inner diameter of 4.8 cm. Either 2 or 3 cores were retrieved at each of 5 or more stations per lake. At least one of the stations was situated such that epilimnetic sediments were obtained.

The cores were sectioned into 1-cm slices to a depth of 20 cm using an extruder and plastic collar (Cross 1977). The 2 or 3 replicate slices collected at each site were combined, dried to constant mass (a minimum of 24 h) at 100°C, and then ground to a fine powder. A subsample of 0.5 - 1.0 g of the dried sample was digested overnight at 70°C in a 2:1 mixture of HCl and HNO₃. Additional information is given in Smith (1983). Analytical methods are described in Ontario Ministry of Environment (1981).

6. Stream Sampling for Chemical Analysis

Stream samples were collected as grab samples with a nalgene bottle, filtered through 102 µm Nitex mesh into the appropriate pre-rinsed sample bottles (Table 5).

Samples were collected from the "A" streams and 9 "export" streams once every two weeks during winter, as frequently as possible (>1/week) during the period of spring melt, and weekly during the remainder of the year. Inlet streams of 6 of the 9 "B" lakes were sampled monthly.

Parameters analysed and analytical techniques were identical to those used for lake water with the following exceptions; analyses of DIC and O_2 , or any of the biological analyses were not performed. The method of calculating the input of material to the lake from the watershed was described in Scheider et al. (1979a).

7. Precipitation Sampling for Chemical Analysis

The types of precipitation collected at each site and periods of collector operation are summarized in Figure 4. Battery operated, moisture-activated samplers (Applied Earth Science Consultants) opened automatically during periods of precipitation and collected the 'wet' fraction of precipitation. Samples were removed from the collectors when there was sufficient volume for all chemical analyses. Collection periods ranged from 1 to 40 days (winter), most samples being collected weekly. One event sampler (Dorset) was electrically heated for winter use. Snow samples were thus melted and kept in the liquid state.

Beginning in 1978, bulk deposition was collected with 0.25 m² Teflon coated, stainless steel funnels leading into glass bottles. In previous years, smaller polyethylene funnels had been used. Funnels were fitted with 500 μ m Nitex mesh to prevent contamination by insects. Samples were visually inspected and any that were obviously contaminated were discarded.

Beginning in the winter of 1978-79, snow samples were obtained with the 0.25 m² Teflon collector, modified for winter use with a wider throat

opening. Prior to this, bulk snow samples had been collected with 63 cm high, 43 cm diameter polyethylene containers. Collection periods for bulk deposition ranged from 1-83 days (winter), most samples being collected weekly or bi-monthly.

All collectors were ≈ 1 m above ground (or snow) level. Rainfall depths used in the calculation of deposition were measured at each site using a 10 cm rain gauge. Snow depths used in deposition calculations were measured with Nipher gauges beginning in the winter of 1978-79. Prior to this, snow samples were melted and their volumes measured to obtain water equivalent depths of snowfall. Calculation of the input of material to the lake from precipitation was carried out using a method similar to that described in Scheider et al. (1979b).

8. Biological Sampling Methods

A. Phytoplankton and Chlorophyll

Phytoplankton and chlorophyll samples were taken throughout the euphotic zone which was considered to be a depth equivalent to twice the Secchi disc depth. In 1982 light profiles were constructed in each lake using a Li-Cor Model 185 light meter equipped with a Li-192 cosine corrected quantum sensor. Measurements were taken immediately above and below the surface and at depths 0.5 m, 1 m, 2 m, etc. until light was undetectable. The lower limit of the euphotic zone was considered to be the depth where light was 1% of readings taken immediately below the surface. This depth closely approximates twice the Secchi depth on most lakes.

Collection of samples for analysis of chlorophyll and phytoplankton was identical to that for chemical samples. All phytoplankton samples were volumetrically combined, preserved with 1-3 mL of Lugol's preservative in a 1 L glass bottle and shipped to the Taxonomy Section of the Ministry of the Environment to be analyzed. The chlorophyll samples were collected in 1 L opaque plastic bottles. At the laboratory in Dorset, each chlorophyll sample was shaken and 5 drops of a 20 g/L MgCO_3 solution was added. A measured volume (500-1000 mL) was vacuum (5-10 psi) filtered through a 1.2 μm Sartorius or Millipore filter paper. The filters were then frozen in aluminum foil covered petri dishes and sent to Toronto for analysis.

Phytoplankton were counted on inverted microscopes by the Utermohl method (Utermohl 1958). In the Utermohl technique, subsamples of the concentrated samples were settled into 2.1 or 5.0 mL Utermohl-type plankton counting chambers. At least one half of the chamber was scanned at 150X for larger phytoplankters. One to several radii were examined at 600X for smaller forms. Between 200 and 400 "units" (cells, filaments or colonies) were counted for each sample, a number that Lund et al. (1958) considered to provide acceptable precision. Nicholls and Carney (1979) list the classical monographs which were routinely employed for identifying the phytoplankton. Dimensions of all counted cells, excluding gelatinous envelopes and chrysophyte loricae were recorded and volumes computed by calculating volumes of most similar geometric shapes. Volumetric data were converted to biomass (as wet weight) assuming unit density.

B. Phytoplankton Production

The radiocarbon method was used to measure phytoplankton productivity because of its sensitivity and accuracy in oligotrophic waters (Schindler and Holmgren 1971). Incubations were performed in situ in the "A" lakes in 1976 and in Red Chalk Lake in 1978.

In 1980 and 1981, phytoplankton productivity of Red Chalk, Plastic and Chub Lakes was measured in light and temperature controlled incubators identical to those described by Shearer (1976).

In situ incubations were of 2-4 hour duration commencing near 9 AM using water collected from and returned to the same six predetermined depths in the euphotic zone. Laboratory incubations (1980 and 1981) were performed using two composite samples, one of the epilimnion, and one through the metalimnion and hypolimnion to the limit of the euphotic zone. These samples were collected by raising and lowering a single 4 L amber bottle through the appropriate depth range. The incubators were set to the average temperatures of the appropriate strata.

For the in situ incubations, two "light" and one dark 250 mL glass-stoppered Pyrex bottle were incubated at each depth. For the laboratory incubations, two 60 mL light bottles (glass-stoppered Pyrex) were filled for submersion at 4 light levels in 1980 and 8 light levels in 1981. Epilimnetic productivity and meta-hypolimnetic productivity were measured on subsequent days.

Samples were inoculated with a variable quantity 0.25 to 1.0 mL of $\text{NaH}^{14}\text{CO}_3$ with a specific activity of $2.49 \mu\text{Ci mL}^{-1}$, after discarding an appropriate volume of sample to prevent overflow of tracer. After incubation, unfixed ^{14}C was removed by the acidification and bubbling technique (Schindler et al. 1972). In 1976 and 1978 the technique was performed as originally described with the single modification of assiduously rinsing the walls of the Allihn tubes with sample prior to removing the aliquot for counting to prevent loss of label to the tube walls (Theodorssen and Bjarnason 1975). In 1980 and 1981 acidification and bubbling was performed directly in the scintillation counting vials (Gachter and Mares 1979) and $^{14}\text{CO}_2$ driven off was trapped in alkali.

Standards were prepared in quintuplicate by dispensing, with an Eppendorf pipette, 50 μL of the $\text{NaH}^{14}\text{CO}_3$ solution into a mixture of 14.5 mL of PCS, a xylene-base scintillation cocktail (Amersham/Searle Corp.) and 0.5 mL of NCS, a quaternary ammonium base. Samples were counted on either a Beckman LS233 or a Packard 3375 Tricarb liquid scintillation spectrophotometer. Efficiencies were checked by external standard channels ratio method.

Samples for chlorophyll and DIC were collected from each incubation depth for the in situ incubations and dispensed from the composite bottle for the laboratory incubations. Analyses were performed as indicated previously.

A computer program similar to that described by Fee (1973), designed to calculate daily integral primary production corrected for morphometry was designed for the in situ incubations. Required inputs were 1) surface irradiances on the day on which incubations were performed, 2) the vertical extinction coefficient of light (k') 3) The time of incubation and calculated volumetric rates of carbon uptake at each depth 4) the maximum depth to which production was to be calculated and 5) the volumes of the lake strata. For the laboratory incubations, light levels and rates of carbon uptake measured in the incubator were required.

Surface irradiances were continuously monitored on a Kipp and Zonen CM-5 Pyranometer equipped from 1976 to 1980 with inner and outer hemispheres of clear glass, uniformly transparent to energy between 300 and 3,000 nm. In 1981 a second pyranometer was employed equipped with a Schott model KG3 coloured glass hemisphere transparent only to photosynthetically available radiation (IPhAR, 300-800 nm).

The strip-chart output was digitized to give hourly average surface irradiances which were converted to subsurface PhAR assuming 6.5% back reflection (Wetzel 1975) and a ratio where necessary of PhAR to measured irradiance of 0.48. PhAR was measured with a Li-Cor model 185 meter equipped with a LI-192 cosine corrected underwater quantum sensor from 1976 to 1980, and an Li-193 SB sphaerical quantum sensor thereafter. Use of the sphaerical sensor in the incubator

obviates the need for application of an incubator light quality correction factor (Fee 1978, Yan et al. in prep).

The computer program generated a vertical irradiance profile for each hour of the day from the surface irradiance data converted to subsurface PhAR, and n' . From n' , the depths of the incubation and the production vs. depth data or from the production and light incubator data the program generated a production vs. irradiance array of numbers which was used to generate an instantaneous vertical production profile for each hour of the day. Integral daily production corrected for lake morphometry for the entire lake (P in mg C day⁻¹) was then calculated as follows:

$$P = \sum_{t=0}^{t=n} \left(\sum_{z=0}^{z=z_{\max}} V_z P_{z_t} \right) \quad (6)$$

where t = time in hours

z_{\max} = maximum depth (in m) of calculation (considered as the maximum depth of the lake or the depth corresponding to 5μ Einsteins m⁻² sec⁻¹ of PhAR, whichever was less)

V_z = volume (in m³) of a lake stratum

P_z = production (in mg m⁻³ hour⁻¹) within a stratum at time t.

Average rates of areal and volumetric production were derived from P by dividing by the lake area and the euphotic zone volume, respectively.

C. Biologically Available Phosphorus (BAP)

Estimates of the phosphorus immediately available to biota in lakes from bulk deposition, wet-only precipitation and streamwater were made using a kinetic bioassay technique outlined in Dillon and Reid (1981).

Bulk deposition, wet-only precipitation and stream samples for the analysis were collected on the same day as the bioassay. During the summer, volume-weighted composite samples of lake water were taken from the epilimnion of the lake to be used for the bioassay medium in the morning of the day that the experiment was carried out. Samples were collected in 40 L acid-washed containers that were rinsed at least five times with deionized, distilled water and twice with lake water. During the winter period of ice cover and the spring and fall turnover periods, lake water was collected from the top 2 m of the water column.

Orthophosphate standards (usually 0, 2.5, 5, 12.5, 25, 50 and 100 mg m⁻³ as P) were prepared at the start of each bioassay using dried (105°C for 24 hr) Na₂HPO₄ and deionized, distilled water (DDW). All glassware was acid-washed and rinsed repeatedly with DDW prior to use.

To 475 mL of lake water in a 1 L Erlenmeyer flask, a 25 mL aliquot of either an o-PO_4 standard or a sample of bulk deposition, wet-only precipitation or streamwater and a 1-mL aliquot containing approximately 2 μCi of carrier-free $\text{o-}^{32}\text{PO}_4$ were simultaneously added. The mixture was continuously stirred and 10-mL aliquots withdrawn at time intervals $t = 30, 60, 120, 180, 300, 420, 600$ and 900 sec. These were quickly filtered through two 0.45μ pore-size membrane filters (Millipore HAWP 04750) and the filter funnel was washed down with 2 mL of DDW. The second or lower filter was used to correct for absorption of $^{32}\text{PO}_4$ on the upper filter paper. At the end of each experiment, the filters were transferred separately to liquid scintillation counting vials (Beckman Poly Q). Quadruplicate unfiltered 1 mL aliquots of the lake water - sample mixture were also placed into counting vials. To each vial, 13.5 mL of PCS (xylene based liquid scintillation cocktail) was added. The entire procedure was repeated using fresh lake water as the bioassay medium for each o-PO_4 standard and each sample of unknown BAP content (stream water, bulk deposition or wet-only precipitation). The vials containing the filters and fluor were counted twice on a Beckman LS233 liquid scintillation spectrometer. The $\%^{32}\text{P}$ remaining in solution was calculated as:

$$1 - \frac{\text{dpm}(\text{sample or upper filter}) - \text{dpm}(\text{control or lower filter})}{10 \times \text{dpm}(\text{sample medium})} \times 100\% \quad (7)$$

The log of the ^{32}P remaining in solution was plotted vs. time, and the initial slope (k') of the log-linear portion of the uptake plot was calculated by regression analysis. The coefficient of determination (r^2) was almost always > 0.99 . In some instances, the entire plot (to $t = 15$ min) was linear, while in others, only the first four or five points (to $t = 3-5$ min) were linear, indicating that either biphasic kinetics (Lean 1973) were occurring or that the asymptotic steady-state distribution of ^{32}P was being rapidly reached. The initial slope of the uptake plot, k' , rather than the actual uptake rate (k), which can be determined from a plot of ^{32}P remaining in solution minus the asymptotic or steady-state distribution fraction versus time, was used so that all seven standards plus several samples of unknown BAP content could be assayed during one day.

The initial slopes for each of the experiments using the standard PO_4 additions were plotted against o-PO_4 added. From this calibration plot, the k' measured using precipitation or stream samples in place of o-PO_4 standards were used to provide an estimate of BAP content of the bulk deposition, wet-only precipitation or streamwater.

D. Zooplankton

From 1976 to the summer of 1978, zooplankton samples were collected with a 30 L Schindler/Patalas trap (S/P) equipped with 76 μm mesh, at odd metre intervals to 1 m above bottom in all lakes.

The samples, collected in 4 oz. glass jars, were preserved in the field with a 4% sugar formalin solution. The S/P trap collections were subsequently pooled in a similar manner to that used for the chemical samples (i.e. to provide a volume weighted composite). In May 1978 a metered tow net (76 μ m mesh) replaced the Schindler/Patalas as the primary sampling gear. The tow net was vertically hauled through a series of specified depths calculated to produce a volume weighted composite sample when all the hauls are combined. Volume of water sampled was determined from the meter.

Chub, Plastic and Red Chalk were also sampled with a S/P trap every week beginning May 1980 and with the metered tow net every other week.

For the summer of 1981 the methods remained the same with the following exceptions. The mesh size of the flowmeter tow net was changed from 76 μ m to 80 μ m and that on the Schindler/Patalas was changed from 76 μ m to 35 μ m for efficient collection of rotifers. In addition a separate study was conducted in 1981 only on Red Chalk Lake to assess zooplankton patchiness. Every 3rd week, triplicate hauls were collected from each of 5 stations in addition to the main station on the lake. In 1982, the mesh on the S/P trap was changed from 35 μ m to 55 μ m.

All samples were preserved with sugar formalin solutions of 4% strength from 1976-1981 and 6% in 1982. Animals collected with the

S/P trap were anaesthetized with carbonated water in 1981 and 1982 prior to preservation to minimize egg loss.

The monographs routinely employed for identifying crustacean zooplankton were those of Edmundson (1959), Brooks (1959) and Deevey and Deevey (1971). Copepod nauplii were counted but not identified. Copepodids were identified to the level of suborder. Three to four hundred crustaceans were usually enumerated in each sample giving a coefficient of variation (V) on the estimate of crustacean density of $\approx 5\%$ of the mean, assuming a Poisson distribution of the animals in the counting chambers ($V = 1/\sqrt{n}$, where n = number of animals). Rotifers were enumerated only for the A lakes and only in 1977.

Individual species biomasses were determined for all the dominant planktonic Crustacea in the study lakes. To do this, 50-300 individuals (depending on their size) were chosen to equally represent all size classes observed in the year. These were removed from the samples, rinsed four times in distilled water to remove adhering preservative, placed on pre-weighed coverslips, dried to a constant weight (≈ 24 h) at 80°C and weighed to the nearest tenth of a microgram on a Sartorius electro-balance. Separate dry weights were obtained for naupliar, copepodid and adult copepods. Rotifer weights were generally taken from Lawrence et al. (in press).

Zooplankton data were routinely reported as density or were converted to biomass using the determined weights. Because the

sampling frequency was not always constant, averages of data for the ice-free season were determined by integration of density or biomass vs. time plots (i.e. averages were time weighted). Additional details on zooplankton methods may be found in Hitchin and Yan (1983).

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Table 1. List and designation of study lakes

Lake	Designation	
	'A' Lake	'B' Lake
Blue Chalk	1976 - present	
Chub	1976 - present	
Crosson	1979 - present	1976 - 1979
Dickie	1976 - present	
Harp	1976 - present	
Heney	1979 - present	
Jerry	1976 - 1980	
Plastic	1979 - present	
Red Chalk (main basin)	1976 - present	
Red Chalk (east basin)	1977 - 1980	
Basshaunt		1976 - present
Bigwind		1976 - present
Buck		1976 - present
Glen		1976 - present
Gullfeather		1976 - present
Little Clear		1976 - present
Solitaire		1976 - present
Walker		1976 - present

Table 2. Summary of selected morphometric data for the study lakes.

	Area (ha)	Mean depth (m)	Maximum depth (m)	Volume (m ³ ×10 ⁵)	Shoreline length (km)
Blue Chalk	49.4	8.5	23	42.1	4.60
Chub	32.2	8.9	27	28.5	3.87
Crosson	56.8	8.4	25	47.7	3.88
Dickie	93.2	5.0	12	46.4	7.84
Harp	66.9	12.4	40	82.6	4.56
Heney	21.7	3.3	6.0	7.24	-
Jerry	50.1	12.4	35	61.9	4.60
Plastic	32.3	8.0	17	25.8	-
Red Chalk (Whole lake)	56.9	14.2	38	80.8	4.82
Basshaunt	47.3	7.7	24	36.6	4.85
Bigwind	111	10.7	32	118	8.24
Buck	40.3	10.9	30	43.9	3.56
Glen	16.3	7.2	15	11.8	1.83
Gullfeather	65.9	4.8	13	31.5	5.26
Little Clear	10.9	8.1	25	8.86	1.48
Solitaire	124	13.3	31	164	5.98
Walker	68.2	6.2	17	42.1	6.44

Table 3. Environment Canada Meteorological Stations used for obtaining hydrometeorological data for study lakes and watersheds

Lake/Watershed	Meteorological Station Used
Harp, Jerry, Walker	Huntsville
Buck, Little Clear, Solitaire	Dwight
Red Chalk, Blue Chalk, Chub, Paint Inlet 1, Trading Bay Inlet 1, Plastic	Dorset
Dickie, Heney	Vankoughnet, Dorset
Bigwind, Gullfeather, Crosson	Vankoughnet
Basshaunt, Glen, Moose Inlet 1, Head Inlet 1, Haliburton Inlet 12	Haliburton
Twelve Mile Inlet 1 North, Twelve Mile Inlet 1 South, Duck Inlet 1, Beech Inlet 1	West Guilford

Table 4. Description of hydrological gauging stations

Stream	Structure	Period of Operation
Blue Chalk 1	Combination 22-1/2° and 90° V notch weir	June 1976-Nov. 1979
	90° V notch weir	Nov. 1980-June 1982
Blue Chalk Outflow	H flume	Sept. 1976-Aug. 1980
	183 cm wide flume with low flow structure	Nov. 1980-June 1982
Chub 1	90° V notch weir	June 1976-Aug. 1980
	90° V notch weir	Nov. 1980-June 1982
Chub 2	Cippoletti weir	June 1976-Sept. 1976
	Cippoletti weir with 120° V notch	Sept. 1976-Mar. 1977
	Cippoletti weir	Mar. 1977-Aug. 1977
	Cippoletti weir with low flow structure	Aug. 1977-Sept. 1980
	91 cm wide flume with low flow structure	Sept. 1981-June 1982
Chub Outflow	120° V notch weir	May 1976-Sept. 1980
	152 cm wide flume with low flow structure	Nov. 1980-June 1982
Crosson 1	244 cm wide flume with low flow structure	Aug. 1981-June 1982
Crosson Outflow	244 cm wide flume with low flow structure	Dec. 1980-June 1982
Dickie 5	90° V notch weir	Aug. 1976-May 1977
	Combination 90° V notch and rectangular weir	May 1977-Nov. 1980
	91 cm wide flume with low flow structure	June 1981-June 1982
Dickie 6	90° V notch weir	Aug. 1976-June 1979
	90° V notch weir	June 1979-June 1982
Dickie 8	H flume	Aug. 1976-June 1979
	H flume with 90° V notch weir as downstream control	June 1979-July 1981
	H flume with rectangular weir as downstream control	July 1981-June 1982

Table 4. Description of hydrological gauging stations (continued)

Stream	Structure	Period of Operation
Dickie 10	90° V notch weir	Aug. 1976-June 1977
	Combination 90° V notch and rectangular weir	June 1977-June 1979
	combination 90° V notch and rectangular weir	June 1979-June 1982
Dickie 11	120° V notch weir with downstream H flume	Aug. 1976-June 1979
	120° V notch weir	Aug. 1979-June 1982
Dickie Outflow	H flume	Aug. 1976-June 1977
	H flume and downstream low flow structure (90°V notch)	June 1977-Apr. 1979
	H flume and downstream low flow structure (90°V notch)	Aug. 1979-June 1982
Harp 3	90° V notch weir	June 1976-June 1977
	90° V notch weir with upstream flume	June 1977-June 1979
	90° V notch weir	June 1979-June 1982
Harp 3A	90° V notch weir	June 1976-June 1977
	90° V notch weir with H flume	June 1977-Sept. 1979
	combination 90° V notch and rectangular weir	Sept. 1979-June 1982
Harp 4	90° V notch weir	June 1975-Jan. 1980
	122 cm wide H flume with low flow structure	Feb. 1981-June 1982
Harp 5	91 cm. wide H flume	Sept. 1976-Aug. 1979
	152 cm. wide H flume with low flow structure	Aug. 1979-June 1982
Harp 6	90° V notch weir	Sept. 1975-Oct. 1980
	90° V notch weir	Feb. 1981-June 1982
Harp 6A	90° V notch weir	June 1976-Aug. 1979
	90° V notch weir	Feb. 1981-June 1982
Harp Outflow	H flume	June 1976-Aug. 1979
	152 cm wide H flume with low flow structure	Aug. 1979-Apr. 1980
	305 cm wide H flume with low flow structure	Feb. 1981-June 1982

Table 4. Description of hydrological gauging stations (continued)

Stream	Structure	Period of Operation
Heney Outflow	152 cm wide flume with low flow structure	Sept.1981-June 1982
Jerry 1	90° V notch weir	Sept.1976-June 1980
Jerry 3	No structure	
Jerry 4	Combination 90° V notch and rectangular weir	Sept.1976-June 1980
Jerry Outflow	H flume	Aug. 1976-June 1980
Plastic 1	combination 90° V notch and rectangular weir	Sept.1979-June 1982
Plastic Outflow	91 cm wide flume with low flow structure	Sept.1979-June 1982
Red Chalk 1	90° V notch weir 122 cm wide flume with low flow structure	June 1976-Apr. 1980 Sept.1980-June 1982
Red Chalk 2	90° V notch weir 90° V notch weir	June 1976-Sept.1980 Nov. 1980-June 1982
Red Chalk 3	120° V notch weir 120° V notch weir 122 cm wide flume with low flow structure	July 1976-June 1978 June 1978-Sept.1980 Sept.1981-June 1982
Red Chalk 4	120° V notch weir 91 cm wide flume	June 1976-Sept.1980 Sept.1981-June 1982
Red Chalk Outflow	120° V notch weir 266 cm wide H flume 266 cm wide H flume with low flow structure 244 cm wide H flume with low flow structure	Jan. 1976-Nov. 1976 Nov. 1976-June 1977 June 1977-July 1979 Sept.1979-June 1982

Table 4. Description of hydrological gauging stations (continued)

Stream	Structure	Period of Operation
Haliburton Lake Inlet 12	120° V notch weir	June 1977-June 1980
Moose Lake Inlet 1	244 cm wide H flume 122 cm wide H flume	Sept. 1976-June 1977 June 1977-June 1980
Twelve Mile Inlet 1 North	H flume 152 cm wide flume with low flow structure	July 1976-Sept. 1980 Dec. 1980-June 1982
Twelve Mile Inlet 1 South	120° V notch weir Combination 120° V notch and rectangular weir	Aug. 1976-Oct. 1980 Dec. 1980-June 1982
Paint Lake Inlet 1	90° V notch weir 90° V notch weir	June 1976-Aug. 1981 Sept. 1981-June 1982
Trading Bay Inlet 1	90° V notch weir	Apr. 1976-June 1980
Duck Lake Inlet 1	90° V notch weir	July 1976-June 1980
Head Lake Inlet 1	90° V notch weir	Sept. 1977-June 1980
Beech Lake Inlet 1	120° V notch weir 213 cm wide flume with low flow structure	Sept. 1976-Oct. 1980 Dec. 1980-June 1982

Table 5 List of chemical parameters measured, sample bottle types, sampling frequency for lake and stream samples (1 = each sampling date, 2 = alternate sampling dates if sampled weekly or each sampling date if sampled 1 per 2 weekly, 3 = 8-10 times yr^{-1} , 4 = 4 times yr^{-1} , 5 = twice yr^{-1}) and location of chemical analysis (D = Dorset, T = Toronto). Bottle codes as in Table 6.

Dates	Parameter	Sampling Frequency	Bottle Code	Laboratory Location	Comment
1976-1979	NH ₃ , NO ₂ , NO ₃	1	1b	D	
1979-1982	NH ₃ , NO ₂ , NO ₃	1	2	D	
1976-1979	TKN, pH, turbidity colour, conductivity	1	2	D	
1979-1982	TKN, colour, conductivity	1	2	D	
1979-1982	pH, TTP, TFE	1	3	D	
1982	"	1	4	D	
1976-1979	dissolved TP	1	5	D	In duplicate
1976-1982	TP	1	5	D	In duplicate
1976-1982	Ca, Mg, Na, K, Cl, SO ₄ , TFE, pH	2	6	T	
1981	Cl, SO ₄ by ion chromatography	2	6	T	
1982	Si	2	7	T	
1982	Si, Ca, Mg, Na, K, Cl, SO ₄ , DOC	2	8	T	
1982	DIC	1	5	D	With gas cap
1982	Al, Mn, Fe, Zn	2	7	T	
1976-1978	Cu, Ni, Zn, Mn, Mo, Al, Cd, Co, Pb	3	9	T	
1978-1982	Cu, Ni, Zn, Al, Pb	4	9	T	
1982	Cu, Ni, Pb, Co, Cd, Cr, As	5	9	T	
1976-1982	O ₂ profile	1	1a	D	
1978-1982	pH profile	1	1a	D	
1981-1982	DIC profile	1	10	D	
1976-1982	Chlorophyll a, b, acid. a	1	11	D/T	

Table 6. Sample bottle codes and preparation.

Bottle Code	Bottle Type	Bottle Preparation
1a	125 mL Prince of Wales	- unique bottle for each lake and depth - prerinsed with sample
1b	125 mL Prince of Wales	- acid bath, D.W. bath, D.W. rinse, rinse with filtered sample (.45 μ m filter)
2	1000 mL plastic	- acid bath (10% HCl) for 6 hours - D.W. bath, D.W. rinse - check conductivity (<1.0)
3	250 mL BOD	
4	250 mL brown nalgene	- D.W. rinse
5	50 mL culture tubes	- autoclaved after each use
6	1 L glass	- pre-rinse with sample
7	250 mL polystyrene	- rinsed in 10% HCl, sample fixed with 1 mL HNO ₃ (after June 1982) - Jan. 1982-June 1982 pre-rinsed with sample for Si only
8	600 mL polystyrene	- pre-rinse with sample
9	500 mL plastic	- acid washed - sample fixed with 1 mL HNO ₃
10	50 mL pyrex tube	- unique bottle for each site, pre-rinse with sample
11	1 L brown nalgene	- pre-rinse with sample

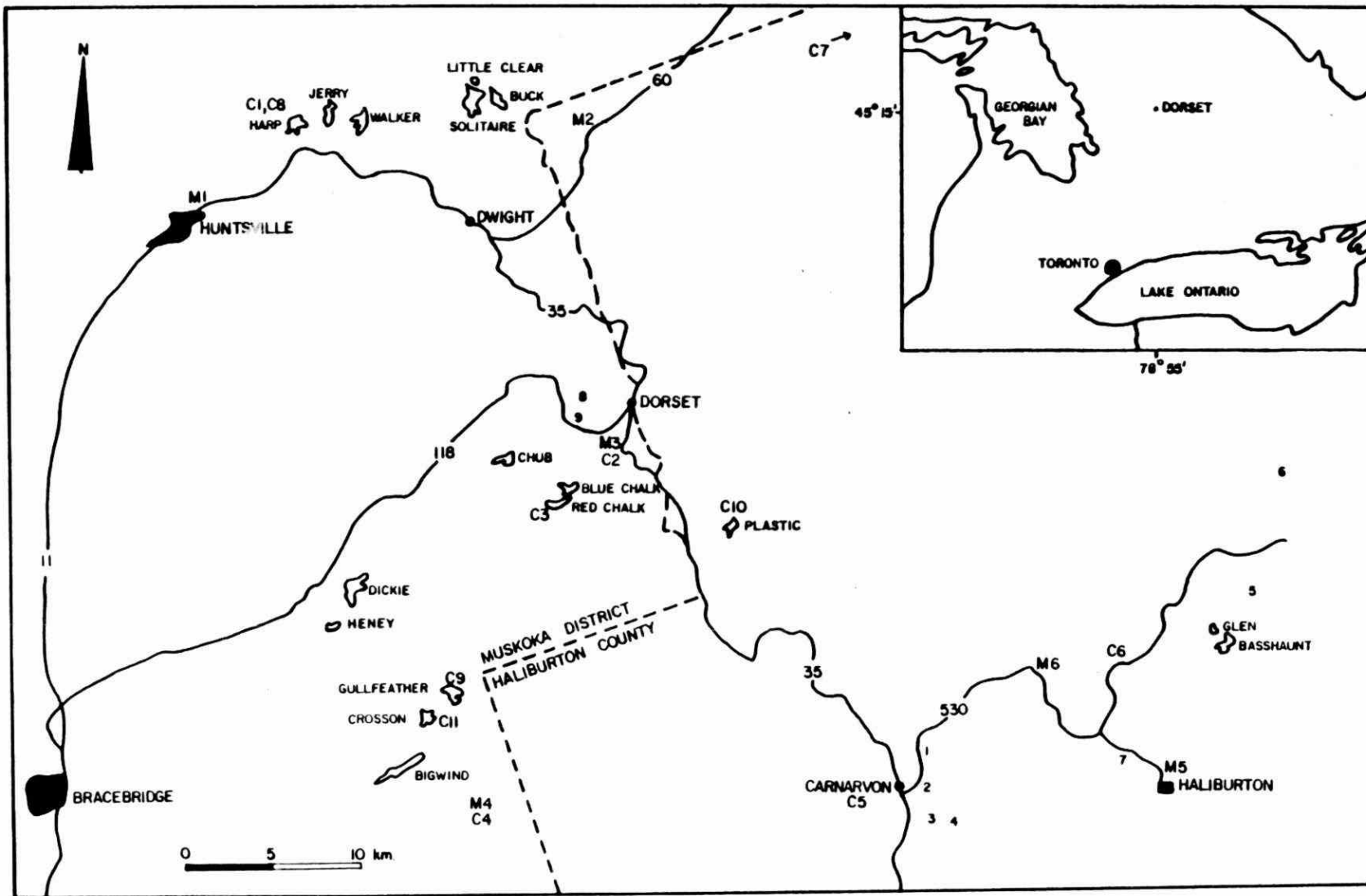


FIGURE 1

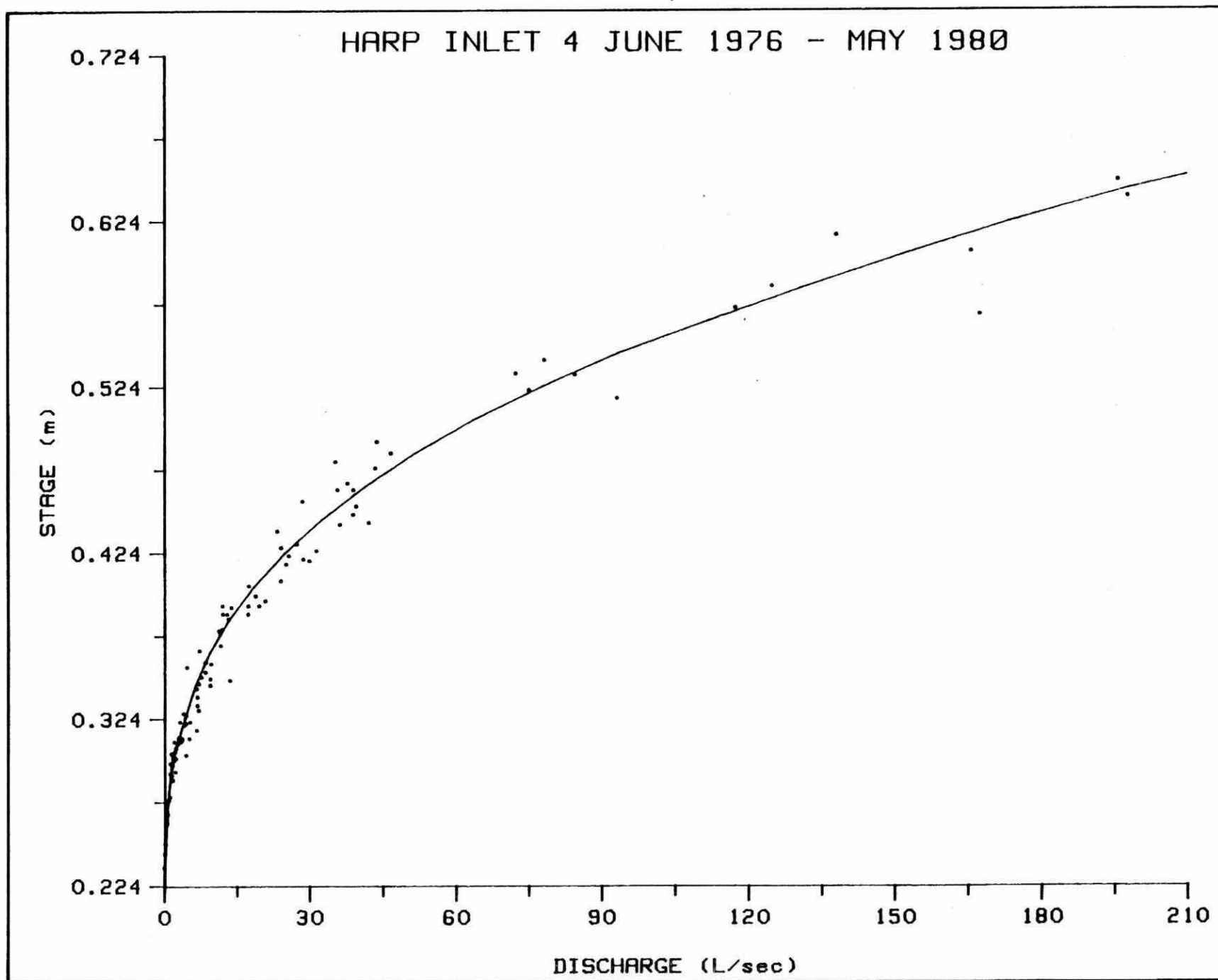
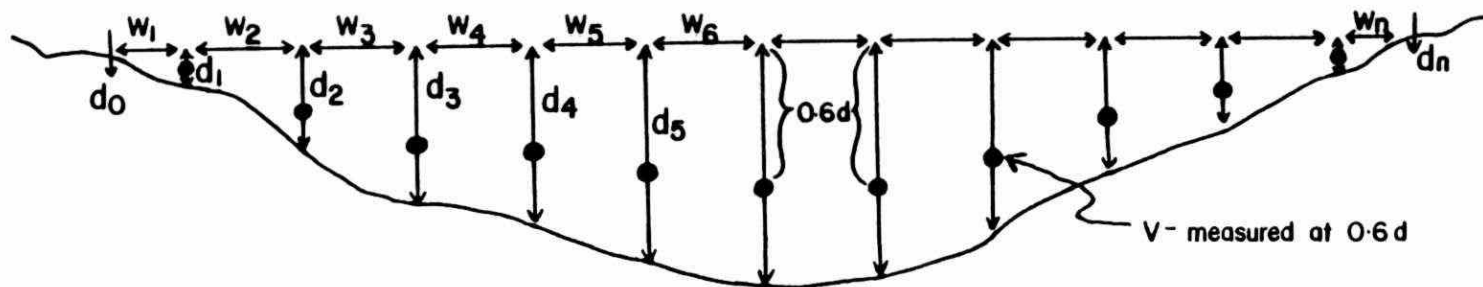


FIGURE 2



$$Q = \sum_{i=1}^n \frac{V_{i-1} + V_i}{2} \cdot \frac{d_{i-1} + d_i}{2} \cdot W_i$$

Q = stream discharge

d = water depth

V = water velocity at $0.6 d$

$V_0 = 0$ at edge of stream

w = distance between adjacent d, V measurements

FIGURE 3

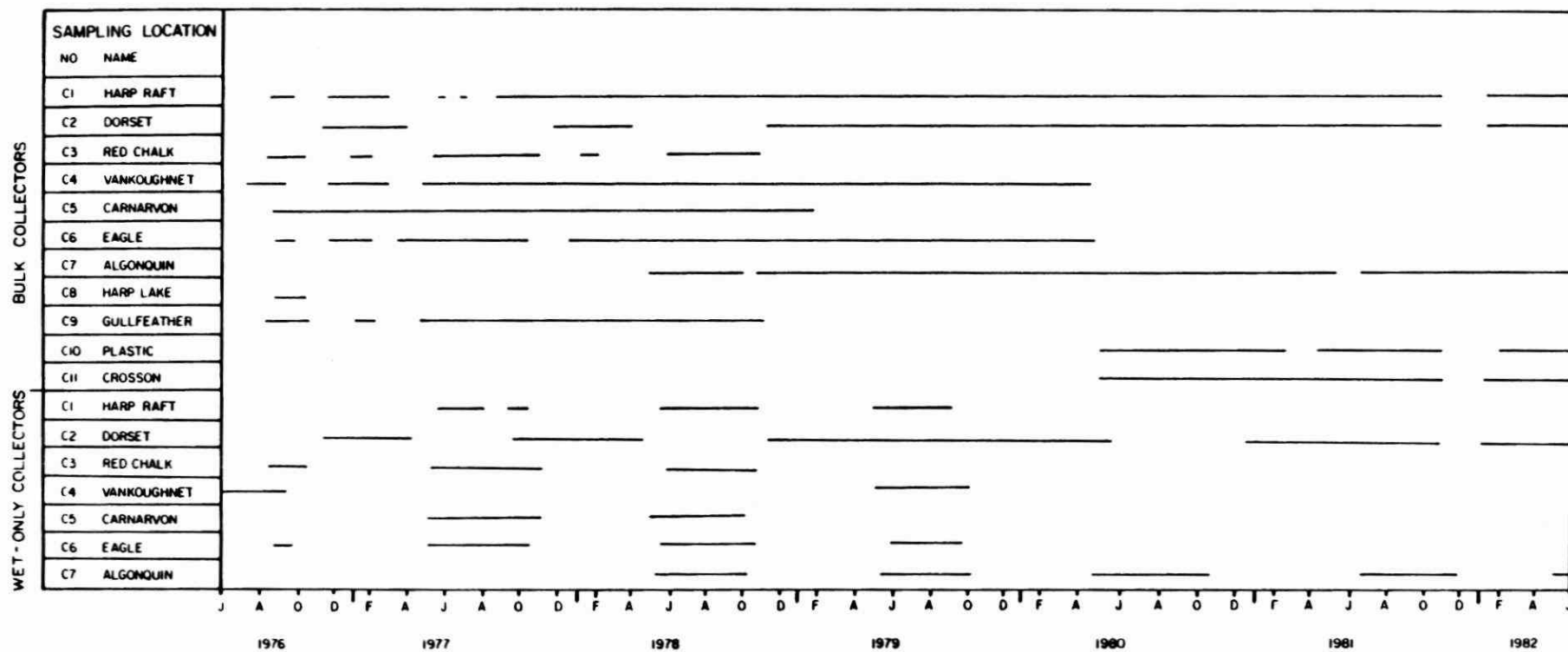


FIGURE 4

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